

## BACKGROUND OF THE INVENTION

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5 Contract No. NAS7-1407.



### RELATED APPLICATION

This application claims the benefit of United States Provisional Patent Application

10 No. 60/264, 556, filed on January 26, 2001, and the benefit of United States Non-Provisional Patent Application No. 09/964, 198, filed on September 25, 2001, the disclosures of which are hereby incorporated by reference.

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### 1. FIELD OF THE INVENTION

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The present invention relates to the field of lasers, and in particular to ring resonator based narrow linewidth semiconductor lasers.

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### 2. BACKGROUND ART

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Light amplification by stimulated emission of radiation, or laser, is making roadways in many facets of our daily lives. For example, lasers can be used in alignment applications

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(to guide machines for drilling tunnels and for laying pipelines), defining targets for military purposes, interferometers (to measure large distances with precision), photography (to simulate a third dimensional depth in holography), medical procedures (to perform surgery on the retina of an eye), communications, and space applications using interferometric metrology and atmospheric spectroscopy, especially in the far infrared 2-3 THz range which requires a very narrow linewidth hybrid semiconductor laser. Even though lasers with very narrow linewidth (10 kHz) are commercially available, they are not tunable over a large range. In order to better understand this limitation of prior art lasers, a thorough understanding of lasers and its various applications are discussed next.

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### Laser

A laser is any class of devices that produces an intense beam of light of a very pure single color. In principle, atoms and molecules exist at low and high energy levels. Those at low levels can be excited to higher levels, for example by heat, and after reaching the higher levels they give off light when they return to a lower level. In ordinary light sources the many excited atoms and molecules emit light independently and in many different colors (wavelengths). If, however, during the brief instant that an atom is excited, light of a certain wavelength impinges on it, the atom can be stimulated to emit radiation that is in phase (in step) with the wave that simulated it. The new emission thus augments the passing wave; if the phenomenon can be multiplied sufficiently, the resulting beam or laser made up of wholly coherent light, is very intense.

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### Prior Art Lasers

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Depending upon the technique used to create lasers, prior art lasers have a vast range of applications, but they all have limitations and drawbacks that make prior art lasers

unsuitable for interferometric metrology, space exploration applications, fiber optics communications, and long distance communications, to name a few.

Liquid lasers made, for example, from a solution of neodymium oxide or chloride in selenium oxychloride, and dye lasers made, for example, from rhodamine 6G and methylumbelliferone mixed with hydrochloric acid suffer from the lack of very fine tuning of the laser beam, especially over large distances needed, for example, in space exploration. Even though the dye lasers can be tuned over a wide spectral range, they are very flimsy and can be only used under laboratory conditions.

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Other lasers, namely the gas discharge lasers which have applications in neon signage, gas dynamic lasers, and chemical lasers not only suffer from the lack of fine tuning of the laser beam, especially over large distances needed, for example, in space exploration, or in situations where a high intensity fine tuned laser beams are needed, but are too bulky and not rugged enough that they have to be handled gently under laboratory conditions. Since the equipment needed to generate these lasers is bulky and occupies a lot of space, it could be critical for certain applications where space and weight conservation are the primary goals.

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Optically-pumped solid-state lasers that have applications in metallurgy where the precise cutting of very hard materials is needed, and in mining of minerals has the disadvantage of frequent breakdown and damage at higher power levels because of the intense heat generated within the laser material and by the pumping lamp. This handicap eliminates this kind of laser from applications which are subject to intense temperature variations. The optically-pumped solid-state lasers also suffer from the drawback of a very narrow tuning range of less than 50 GHz.

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Free-electron lasers are more efficient than any of the previously mentioned variety in producing laser beams of very high power radiation. Furthermore, these devices are tunable, so that they can be made to operate at microwave to ultraviolet wavelengths. But since the laser beam is generated using free electrons from a particle accelerator or some similar source and passed through an undulator (a device consisting of a linear array of electromagnets), it makes the entire device very bulky and heavy to transport, for example in a module used for space exploration. Furthermore, the entire device has to be kept stationary so that the electromagnets are not influenced by any external forces. These limitations narrow the range of commercial applications for this kind of laser.

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Semiconductor lasers are another kind of lasers. Semiconductor lasers consist of a flat junction of two pieces of semiconductor material, each of which are treated with a different type of impurity. When a large electrical current is passed through such a device, laser light emerges from the junction region. This kind of laser suffers from low power output, but the low cost and small size makes these devices suitable for use as light sources, even though it's in a limited commercial market comprising of optical fiber communication and compact digital audio disc players.

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R. Kazarinov, C. Henry, and N. Olsson in their paper titled "Narrow-Band Resonant Optical Reflectors and Resonant Optical Transformers for Laser Stabilization and Wavelength Narrow-Division Multiplexing" published in the IEEE Journal of Quantum Electronics (1987), QE-23, on pages 1419 through 1425, and incorporated herein as reference, have proposed a new way of making resonant integrated optical circuits, which are based on a weak side-by-side coupling between waveguides (pipelines for the transmittal of the laser light) and high Q distributed Bragg resonators. Using their proposed mathematical calculations, it is possible to create a narrow linewidth hybrid (the coupling of active internal elements that make laser light and passive external elements, for example a Bragg grating

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written on a waveguide) semiconductor laser. But units made using the narrow-band resonant optical reflector technology proposed by R. Kazarinov, C. Henry, and N. Olsson are not rugged enough for use as communications hardware or in space applications.

5 Other prior art schemes of making lasers include external elements using silicon and doped silicon dioxide light guides or waveguides with Bragg gratings. Waveguides made with these materials have much larger modes (Modes are specific patterns that the laser light follows. Each waveguide has the ability to propagate a well defined pattern called its waveguide mode) than the standard gain chips (which are the active internal elements that  
10 produce the laser light). This necessitates the use of gain chips with mode converters (which are elements that tune the mode of the waveguide so that there is minimal loss of light at the interface of the waveguide and the laser due to mismatch of their respective modes), which are not only expensive, but not readily available.

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15 Other lasers, namely the narrow linewidth semiconductor lasers utilizing integrated optical external feedback elements have been demonstrated by Ackerman et. al. in their paper "Compact hybrid resonant optical reflector lasers with very narrow linewidths", Appl. Phys. Lett. 58 (5) on pages 449 through 450 (1991), and by Korotky et. al. in their paper  
20 "Integrated-optic, narrow-linewidth laser", Appl. Phys. Lett. 49 (1) on pages 10 through 11 (1986), and incorporated herein as references. Both these references use a resonant optical reflector (ROR) as a means of the linewidth narrowing. The RORs produced by the first reference prove difficult in fabrication due to low tolerance in the relative positioning of the two gratings comprising the resonator. The second reference implements RORs requiring a complicated electro-optic phase control. Both these reference are hence unsuitable for  
25 applications such as interferometric metrology, spectroscopy, or coherent optical communications.

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